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Construction of Automatic Bell Siphons for Backyard Aquaponic Systems

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Aquaponics is a developing agricultural technology that is rapidly gaining worldwide popularity, both for commercial production and small-scale, backyard systems. The aquaponics concept involves integrating aquaculture and hydroponics, where fish wastewater is utilized as a nutrient source for plants grown in soilless culture. Publications describing a high-yield aquaponic lettuce production system and detailing on-farm food-safety practices for aquaponics have recently been issued by CTAHR.[1,2] These efforts are consistent with the college's 2010 Plan of Work[3] and Hawai‘i's 2050 Sustainability Plan,[4] which focus on decreasing the state's reliance on food imports by producing more food locally.

Alhough the integration of agriculture and aquaculture has been practiced globally in one form or another by many indigenous cultures for thousands of years, modern aquaponics (applying modern materials and tools such as metals, plastics, and electricity) has been developing and practiced for only about the last 40 years, beginning with experiments at the New Alchemy Institute in the early 1970s.[5] The two major types of modern aquaponics are deep-water, or "raft," aquaponics and reciprocating, or "ebb-and-flow," aquaponics.[6] Ebb-and-flow aquaponics is based on a "flood-and-drain" concept in which fish effluent water is pumped through a solid hydroponic support medium (e.g., gravel, expanded clay balls, or cinder rock; see Photo 1). As this nutrient-rich water is cycled through the system, the medium is completely flooded and then drained at short intervals. The solid support medium serves the dual purposes of providing structure for plant roots to grow in and surface area allowing proliferation of aerobic nitrifying bacteria, which are essential for converting nitrogen in the effluent to forms suited to the plants' nutrient uptake.

Flood-and-drain cycling in ebb-and-flow aquaponic systems can be controlled by electronic timers, which regulate the activity of water pumps, or by non-mechanical devices called automatic siphons. These "autosiphons" start and stop on their own, depending on the level of the water surrounding them.[7,8] One of the simplest and most reliable types of autosiphon is called the bell siphon, and while many examples of these can be found on the Internet, how they are made and operated are among the questions most frequently asked of CTAHR's aquaculture extension workers. This publication describes how to construct, size, and troubleshoot an automatic bell siphon for use in a small-scale backyard aquaponic system.

Bell siphon theory

A bell siphon consists of several components, beginning with a vertical standpipe (schedule 40 PVC) that projects upward from a bulkhead fitting in the bottom of the aquaponic grow-bed. The standpipe regulates the maximum water level in the grow-bed. A drainpipe extends from the bottom of the bulkhead to the fish-rearing tank. As the water level in the grow-bed exceeds the height of the standpipe, the water overflows through the inside of the standpipe and the drain directs the flow of water to the fish-rearing tank. An additional pipe (the "bell"), which has a diameter twice that of the standpipe and is slightly longer than the standpipe, is fitted and glued with a cap on one end. Notches, or "teeth," are cut into the bottom end of the bell, and it is placed teeth-down over

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1. Three commonly used solid support media for ebb-and-flow aquaponic systems. Black cinder (left) and pea gravel (center) are produced in Hawai‘i; the expanded clay balls (right) typically are imported from Germany.

the standpipe. A hole is drilled in the capped end of the bell, and an air tube is inserted into the hole. This air tube, or "snorkel," acts as a means to break the siphon; it extends down the length of the bell, ending just above the level of the teeth.

How a bell siphon works

- As the water level rises in the grow-bed, water is forced through the teeth on the bottom of the bell and up between the walls of the standpipe and bell.
- As the water level exceeds the height of the standpipe and the drain begins to fill, a siphon is created.
- Most of the water in the grow-bed is then drained by the siphon until the water level reaches the height of the teeth and tip of the snorkel.
- Air is then forced through the snorkel, and as a result the siphon is broken, resulting in the grow-bed beginning to fill again; the cycle then repeats itself.

Sizing bell siphons and drains

Before constructing a bell siphon, you need to decide which size of drain is appropriate for your grow-bed. The appropriate size of the bell siphon depends on the size of the individual grow-bed. In general, the larger the grow-bed, the greater the volume of water it can hold, and a larger standpipe and bell siphon is necessary to drain it. The recommended ratio of bell siphon size to drain is 2:1; that is, the diameter of the pipe used to build the bell siphon should be twice that of the standpipe (e.g., if the standpipe is ½ inch in diameter, the bell siphon should be made using a 1-inch diameter pipe). The table below shows some sizing parameters for square and rectangular tanks (all approximately 1 ft deep) used successfully by CTAHR researchers, and examples of bell siphons and accompanying drains are shown in Photo 17.

Measurements of bell siphon components for tanks of various sizes diameters (inside = ID, outside = OD) in inches

Bell pipe diameter	1	2	3	4
Standpipe/drain size (diameter)	½	1	1½	2
Snorkel tube size (diameter) and material	3⁄16 OD × ⅛ ID vinyl tubing	7⁄16 OD × 5⁄16 ID vinyl tubing	⅝ OD × ½ ID vinyl tubing	⅞ OD × ½ ID PVC pipe
Dimensions of grow-bed	1 × 4 × 1	4 × 4 × 1	4 × 6 × 1	4 × 8 × 1
Approximate volume of grow-bed	4 ft^3, 30 gal	16 ft^3, 120 gal	24 ft^3, 180 gal	32 ft^3, 240 gal

2. Installing a Uniseal fitting and standpipe in the grow-bed. Drill an appropriate size hole and insert the Uniseal in it; push the standpipe into the fitting and adjust the standpipe height to the desired level.

Installing the bulkhead fitting and standpipe

Once you have decided on the appropriate drain size for your grow-bed, proceed with the following steps:

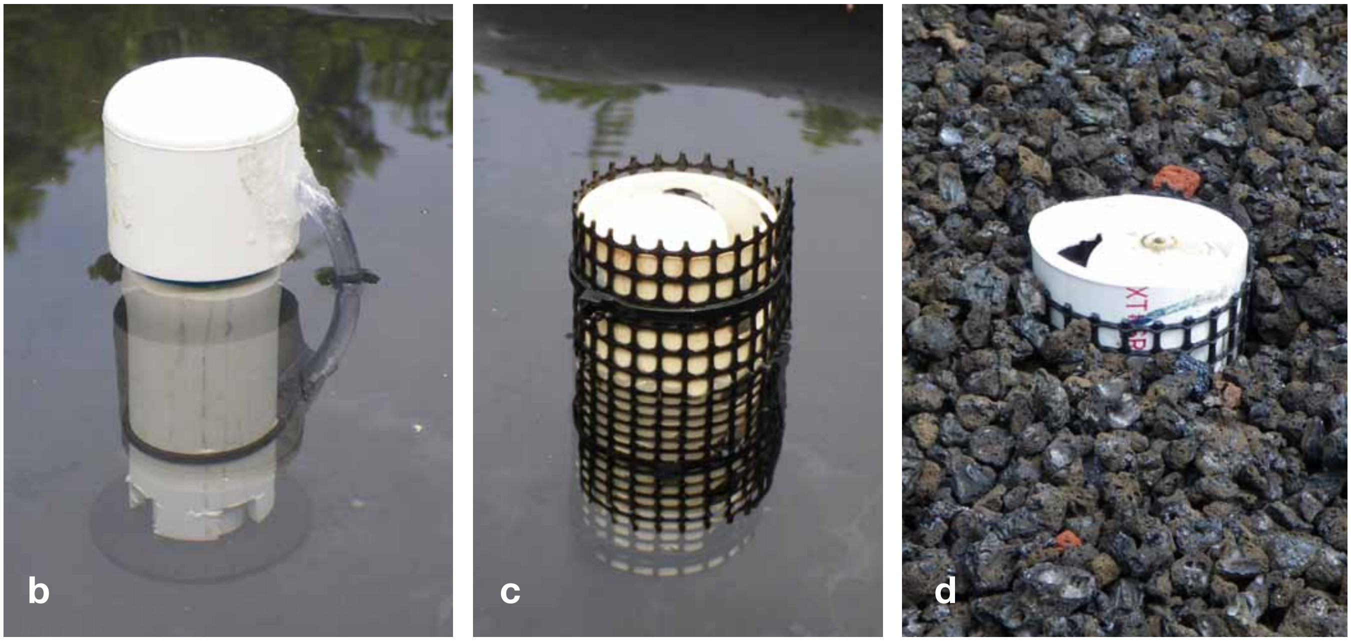
Step 1

Install a bulkhead fitting that will hold the standpipe in the grow-bed and drain the water into the fish tank. Uniseal® fittings (PIPECONEX Universal Pipe Connectors, Uniseal Inc.) are suggested for use as the bulkhead in backyard aquaponic systems because of their low cost and ease of use. As shown in photo series 2, above, use a hole-saw to drill a hole in the bottom of the grow-bed container. A chart of fitting sizes and their appropriate hole-saw dimensions is available from the manufacturer[9] or fixture distributors.[10] Next, push the fitting into the hole. Once the fitting is secure, push the standpipe through the fitting far enough so that a portion of the standpipe extends both above and below the plane of the bottom of the grow-bed.

Step 2

Adjust the height of the standpipe in the grow-bed to the desired water level (Photo 3a). The height of the standpipe dictates both the height of the water level and the height of the bell siphon (Photo 3b). Keep in mind that when the grow-bed is filled with medium (Photo 3c,d), the

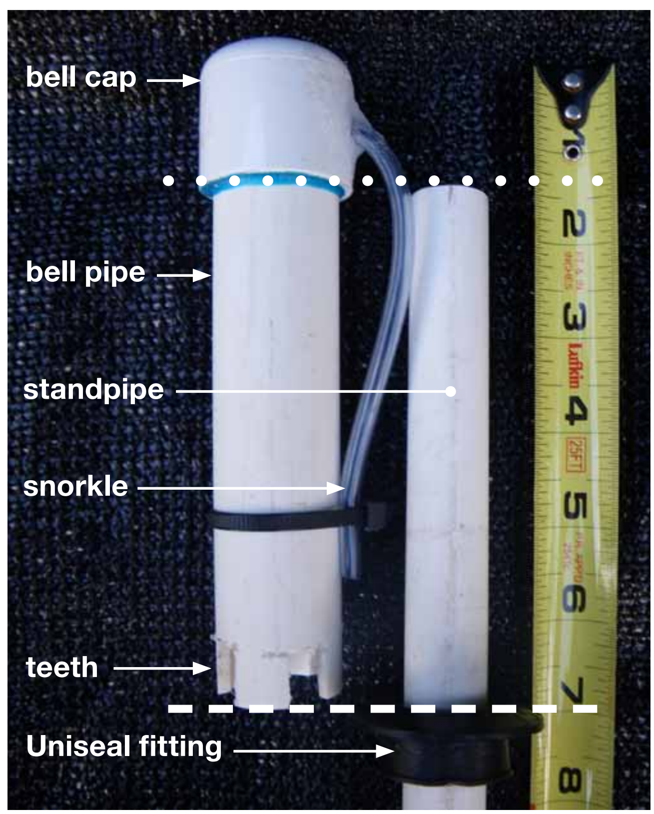
3a. The standpipe height determines the maximum depth of water in the grow-bed.



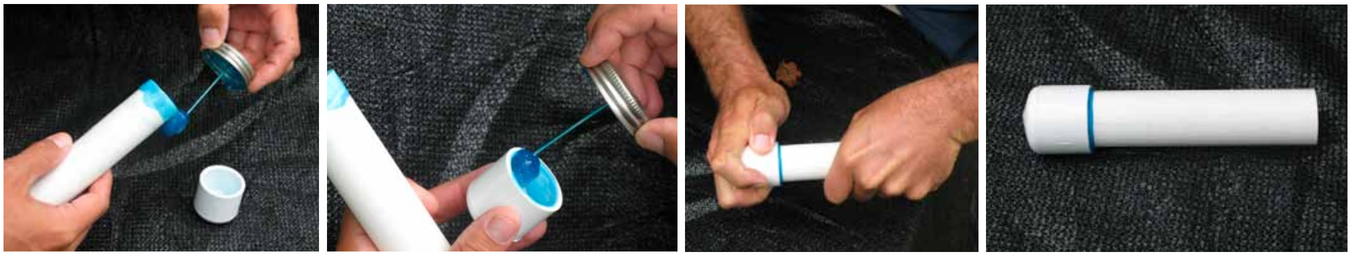
3b–d. The bottom of the bell cap is even with the height of the standpipe, and thus with the desired water level. This level should be predetermined so that when the gravel guard is installed (center) and the medium is added (right), the water level is 1–2 inches below the surface of the medium.

maximum water level should remain 1–2 inches below the surface of the medium. This ensures that algae and unwanted weeds will not grow.

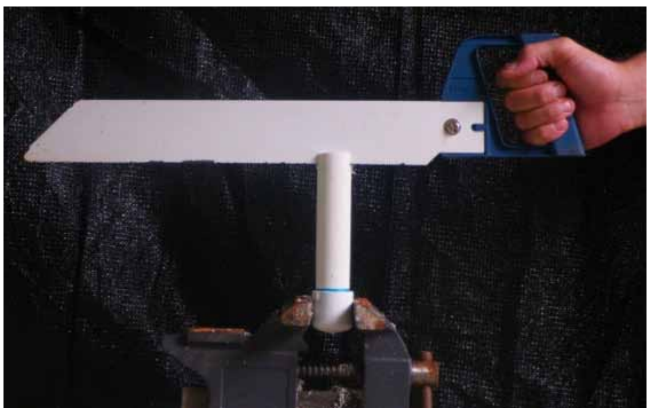
Note: The top of the standpipe should be level with the bottom edge of the cap on the bell siphon. For example, if the ½-inch diameter standpipe is 5½ inches tall and the cap glued on the end of the 1-inch diameter bell pipe is 2 inches long, then the length of the entire bell (pipe + cap) should be 7 inches, and the teeth should rest on the top of the fitting (Photo 4).



4. Components of a bell siphon and companion standpipe with Uniseal fitting. The dotted line represents the maximum water level in the grow-bed; note that it is even with the top of the standpipe as well as the bottom of the bell cap. The dashed line represents the minimum water level or the bottom of the grow-bed; note that the dashed line is even with the top of the Uniseal fitting and the bottom of the teeth.



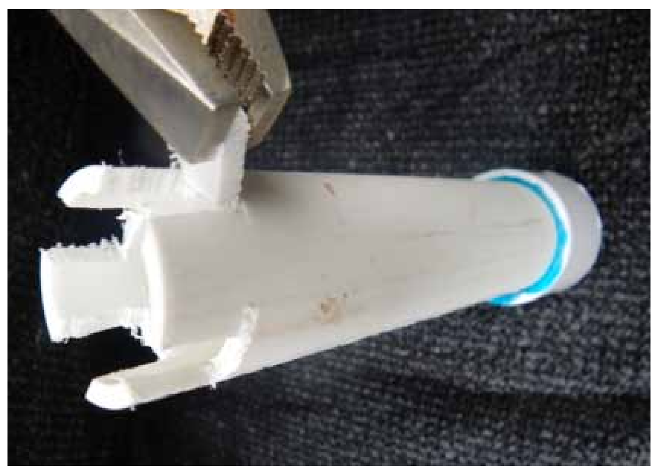
5. Attach the bell cap to the bell pipe with PVC primer and glue. After priming the inside surface of the cap and the outside surface of the pipe, apply glue to the rim of the pipe and the inside of the cap, as shown. Then, push the cap onto the pipe and twist the cap a quarter turn to seal the join. Make sure the seal connecting the cap to the bell tube is airtight.



6. Cut notches to make teeth on the bottom of a bell tube. This can be done with various tools and methods.

7. Notches, before the spacers between the teeth are removed.

8. Make lateral cuts to weaken the spacers between the teeth.



9. Remove the spacers between the teeth with pliers. If cut properly, the spacers break off cleanly with ease.

Bell siphon construction

Step 1

Prime and glue a PVC cap onto the end of the bell pipe (Photo 5). Next, cut the pipe to the appropriate length (again, based on the height of your standpipe), and cut notches (or "teeth") into the bottom of the bell pipe. This can be done by securing the capped end of the bell pipe in a vise, and making two sets of two straight cuts perpendicular to each other across the open end of the pipe using a saw (Photos 6 and 7). Additional cuts should then be made on the lateral surface of the bell pipe at the apex of the first cuts to loosen the teeth (Photo 8). Pliers can be used to gently break away the material between the teeth, revealing the spaces through which the water will flow (Photo 9).

Step 2

Once the teeth have been cut in the bottom of the bell pipe, the snorkel that will ultimately break the siphon must be made. Depending on the size of your bell siphon, use a drill bit or hole-saw with a diameter approximately the same size as the tubing or pipe (Photo 10), and drill a hole into the side of the cap that makes up the end of the bell (Photo 11). Next, push the tubing or pipe through the hole so that the tubing penetrates the inside of both the cap and pipe wall of the bell, and extends ¼ inch inside the bell cap (Photo 12). Using a bead of 100% silicone, seal the gap surrounding the tubing at the entrance to the bell, and allow this to dry completely (Photo 13). It is important to create an airtight seal, because if air enters the top of the bell through the space around the snorkel during use, the siphon will not start properly.

After the seal has dried, gently train the snorkel along the length of the bell pipe and secure the snorkel in place with a cable tie, then cut the free end of the snorkel so that it ends above the teeth (Photo 14). If the snorkel is cut too long (i.e., the open end of the snorkel is lower than or even with the height of the teeth), the siphon will not break properly.

An alternative approach to snorkel design is to drill a threaded "tap"-hole in the bell pipe and screw a 90° hose barb fitting into place. This way, the snorkel tube can extend directly down along the bell pipe toward the teeth without having to make a sharp turn. The absence of a silicone seal and the lessened stress on the vinyl tubing should extend the life of the bell siphon. An example of this design can be found in Photo 17 (the 4-inch bell siphon was built using a ½-inch 90° PVC elbow and straight pipe).

Step 3

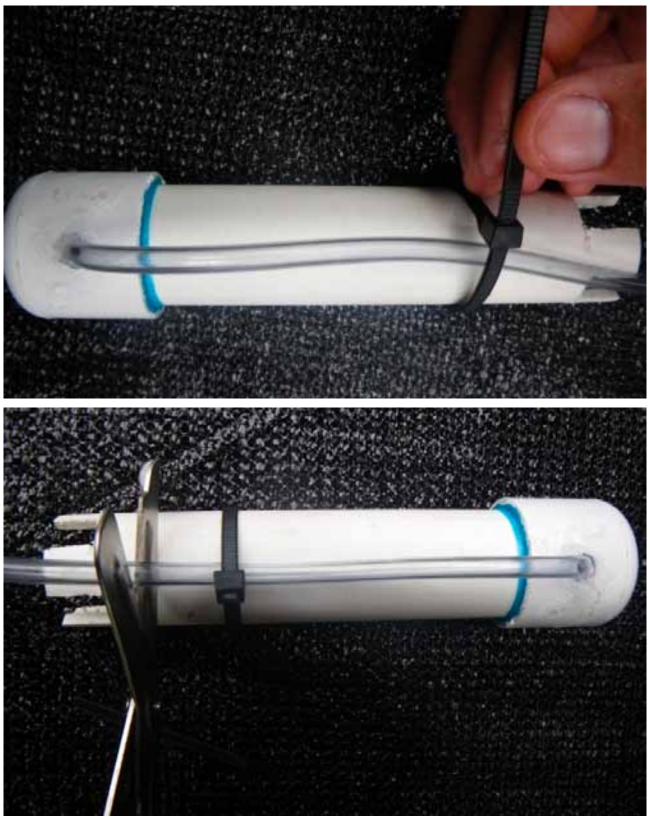
Once the bell siphon is completed, a "gravel guard" should be constructed. This is a porous tube placed around the standpipe and bell siphon before adding the solid support medium to the grow-bed. The function of the gravel guard is to prevent the support medium from clogging the standpipe and bell siphon while allowing water to easily flow through. The gravel guard allows easy access and maintenance to the bell without having to remove or dig through the medium. Although a gravel guard is not necessary for bell siphon function, it is well worth the extra investment of time and materials for the added benefit of ease of maintenance. Particles from the grow media can easily obstruct the teeth and

10. Choose the appropriate size (diameter) drill bit or hole-saw for making the snorkel. The hole drilled in the bell pipe should be only slightly larger than the diameter of the tubing itself, to ensure a tight seal.

11. Drill a hole in the bell pipe for the snorkel tube.

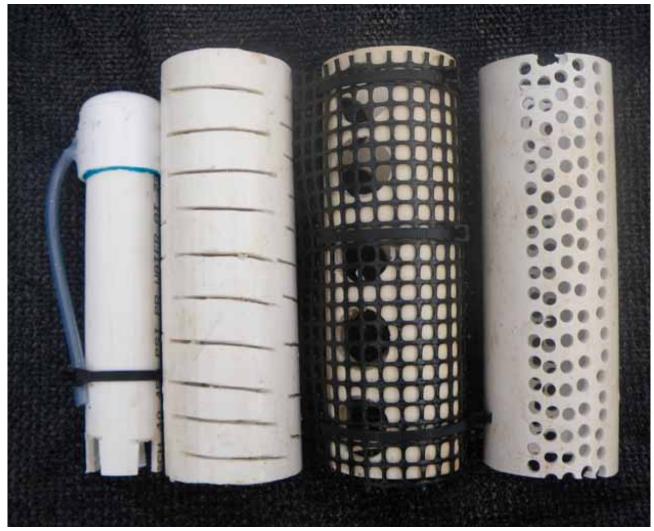
12. Push the snorkel tubing through the bell pipe cap assembly.

13. Seal the junction of the snorkel tube and bell pipe with 100% silicone. Ensure that the seal is airtight.



14. Tie the snorkel tube to be bell pipe (above) and trim it (below). The bottom end of the snorkel tube should be above the teeth to ensure that air bubbles enter the bell siphon at the right time.

snorkel of the bell siphon. Gravel guards can be built in various ways, the simplest being with straight PVC pipe with holes or slits drilled or cut along its length to promote unrestricted water flow. Gravel guards should be approximately twice the diameter of the bell siphon, so that the bell siphon with its protruding snorkel can easily be moved on and off the standpipe during normal system operation and maintenance. Gravel guards should also be



15. Different styles of gravel guard.

slightly longer than the bell siphon, so that they are able to keep out particles of the support medium (e.g, gravel or cinder) that surrounds the drain assembly (Photo 15).

Step 4

When construction of both the bell siphon and gravel guard is finished, the completed autosiphon array can be assembled over the standpipe in the grow-bed. Place the bell pipe over the standpipe so that the teeth rest evenly on the bulkhead or fitting on the bottom of the grow-bed (see Photo 3). Next, place the gravel guard over the bell siphon (Photo 3). Solid hydroponic support media (such as cinder, gravel, or clay balls) should be thoroughly rinsed and then added to the grow-bed. Carefully add the medium around the base of the gravel guard so as not to disturb its placement. Once a firm base of medium has been added around the gravel guard, continue filling the rest of the grow-bed to a height about 1–2 inches higher than the top of the bell siphon (Photo 3). This added height of cinder ensures that the ebbing water in the grow-bed is not exposed to sunlight before the system flushes, which helps prevent algal growth in the grow-bed.

Step 5

Finally, assemble the drain extending from the bottom of the standpipe on the underside of the grow-bed. Add a 90° elbow to the bottom of the standpipe (Photo 16). Extend this elbow with a length of straight pipe sufficient

16. The drain assembly on the underside of the grow-bed. Note the two sequential 90° elbow fittings, which help start and stop the siphon and direct the flow of water back to the rearing tank beneath the grow-bed.

to overhang the fish tank. Add an additional 90° elbow fitting to the end of the straight pipe, facing directly down into the fish tank. A short "nipple" (small piece of straight pipe) added to the open end of this elbow is helpful in directing the flushing water stream. The bends in the drain created by the elbows assist the bell siphon in starting and stopping the flow of water by providing resistance to the water exiting the grow-bed.

General "rules of thumb"

Bell siphons for ebb-and-flow style hydroponic and aquaponic production systems have been in use for several decades, and many variations of these devices are found in practice (see References and Resource sections). Following are some strategies developed at CTAHR for bell siphon design and construction; they result from much trial-and-error experimentation. These rules are meant as guidelines, and they may be modified and improved upon in the future.

The height of the standpipe in the grow-bed should be level with the bottom of the cap on the bell pipe (Photo 4). This relationship of standpipe to bell pipe height is important in ensuring that the volume of air resident in the top of the bell pipe is sufficient to start the siphon. The "double-double rule" is that the diameter of the gravel guard should be at least double the diameter of the bell pipe, which is double the diameter of the standpipe (Photo 15).

The drain assembly (consisting of the plumbing on the underside of the grow-bed extending from the bottom of the standpipe) should contain two 90° elbow fittings in series connected by a length of straight pipe (Photo 16). This arrangement is necessary to restrict the flow of water moving through the drain, and it assists both the starting and stopping of the siphon. An alternative approach is to add a reducer fitting to the bottom end of the standpipe, which acts in a similar way.

How fast water flows into the grow-bed will determine the duration of the cycling of the system. In other words, the faster water is added to the grow-bed, the faster it will fill up, and the shorter the duration between flushes. In general, ebb-and-flow cycles in grow-beds should be about 15–20 minutes, regardless of the size or volume of the grow-bed. This means that you should adjust the flow water into the grow-bed (usually with a ball valve) so that the bell siphon starts, drains, and stops every 15–20

17. Four sizes of bell siphons with accompanying standpipe and drain assembly. From left to right: ½-inch standpipe with 1-inch bell pipe; 1-inch standpipe with 2-inch bell pipe; 1½-inch standpipe with 3-inch bell pipe; 2-inch standpipe with 4-inch bell pipe. Note that the top of the standpipe should be even with the bottom rim of the bell pipe when fully assembled in the grow-bed.

minutes. Also, the depth of the growth media should be between 8–12 inches for optimal filtration and plant growth.

Troubleshooting

Following is a brief outline for dealing with some of the most common problems and issues that have been encountered with new bell siphon construction. It must be stressed that this is not by any means an exhaustive guide to bell siphon construction, and any project involving water and live animals requires significant attention and care.

Problem: The bell siphon will not start; the water level in the grow-bed remains high and does not flush.

Solutions:

1) Check the seal around the snorkel where it enters the bell, or the seal connecting the cap to the bell pipe. These two seals must be airtight, otherwise the vacuum that initiates the siphon action will not form.
2) Ensure that the bell siphon and gravel guard are firmly in place at the bottom of the grow-bed. Pieces of cinder or gravel may move under or through the gravel guard and come to rest between the teeth and tank bottom, causing the space between the bell and standpipe to expand. This added space can prevent the siphon from starting or interrupt its operation in other ways.

Problem: The bell siphon will not stop; the water in the grow-bed remains very low, water is constantly trickling out of the drain, and the tank does not fill back up.

Solutions:

1) Check the snorkel for obstructions. If the opening of the snorkel is pinched or blocked by cinders or biological material, air will not be able to move freely through it to break the siphon. Clear the snorkel, lift the bell siphon out of the grow-bed to manually break the siphon, and then replace it in the gravel guard to continue the cycle.
2) Check the height of the snorkel tube opening. If the snorkel tube opening is too low (i.e., too close to the teeth), it may not provide enough air injection to break the siphon. Try cutting the snorkel tube slightly shorter and see if it works. Repeat this step if necessary, as this is a common solution to this issue.
3) Adjust the drain. Try different combinations of pipe lengths between the 90° elbow fittings on the underside of the grow-bed. Often a slightly longer or shorter vertical or horizontal drainpipe can fix the problem with no other alterations.
4) Check the incoming flow rate. If the rate of water flow coming into the grow-bed is too great, the siphon will have difficulty draining the tank. This is rarely the cause of the problem, but it is worth investigating if all of the above solutions do not work.

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Notes